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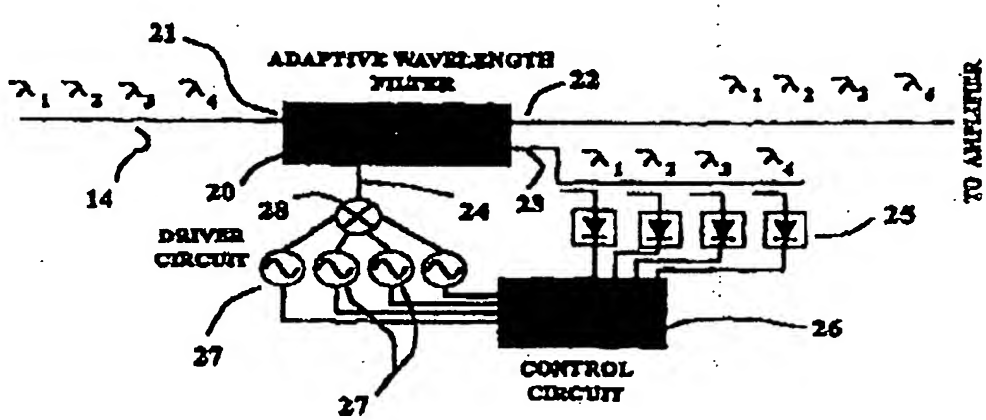


power eg

(57) Abstract

A method of and apparatus for controlling the relative amplitudes of the individual wavelength components of a wavelength division multiplexed optical signal (14) employs an adaptive optical wavelength filter (20) through which the optical signal (14) is transferred. The filter (20) is controlled dependent upon an analysis of the powers of the individual wavelength components (λ_1, λ_2...) of the optical signal so that the output powers may be balanced to have some predetermined relationship. One of a plurality of in-line optical filters, a demultiplexer and a further adaptive optical wavelength filter may be employed to analyse the powers of the wavelength components of the optical signal.

good

METHOD FOR INDEPENDENTLY CONTROLLING THE WAVELENGTH COMPONENT POWERS IN AN OPTICAL WAVELENGTH DIVISION MULTIPLEXED TRANSMISSION SYSTEM

This invention relates to a method of and apparatus for controlling the relative amplitudes of the individual wavelength components of a wavelength division multiplexed optical signal.

The use of wavelength division multiplexing on optical communications systems is rapidly expanding in order to increase the information carrying capacity of a system. In addition, such multiplexing also allows the provision of network switching and protection functions in an effective and economic manner. A wavelength division multiplexed optical signal propagated along optical fibre carries several channels at different wavelengths. At transmission, the wavelength component for any one channel normally has the same amplitude as that of the other channels, but as these wavelength components are processed through a network, the relative amplitudes of the channels become unbalanced.

The optical power per channel at key points in a network will vary depending upon the path taken to reach a given key point. Moreover, the optical power will vary dynamically should network reconfiguration or re-routing take place. Any initial wavelength imbalance in a transmitter will exacerbate the variation in channel optical power following processing of the optical signal through the network.

A further problem is that a typical optical amplifier has a non linear transfer function, in that the gain varies dependent upon the wavelength being amplified. If a wavelength division multiplexed optical signal is passed through such a non linear amplifier, any imbalance in the input signal will be worsened, so degrading the network performance.

The present invention aims at providing both a method of and apparatus for addressing the difficulties

arising from optical power variation across the channels of a wavelength division multiplexed optical signal consequent upon the propagation of the wavelength components of that signal through a network.

According to one aspect of the present invention, there is provided a method of controlling the relative amplitudes of the individual wavelength components of a wavelength division multiplexed optical signal, in which method the wavelength division multiplexed optical signal is processed through an adaptive optical wavelength filter, the relative powers of each wavelength component of the optical signal are determined, and a complex control signal is supplied to the adaptive optical wavelength filter which control signal includes a control component for each wavelength component of the multiplexed optical signal, the magnitude of each control component being adjusted dependent upon the determined power of the respective optical signal wavelength component.

The present invention makes use of the transfer characteristics of an adaptive optical wavelength filter, known per se. Embodiments of such filters include acousto-optic and electro-optic tunable filters. In the case of either of these types of filter, there is an optical waveguide for an optical signal and the transfer function for an optical signal is defined by virtue of a stress-induced birefringence. The interaction between the optical signal and the stressed waveguide results in a polarisation conversion of the optical signal. As a result, if polarisation selective elements are added before and/or after the interactive section of the filter, the passband on the (or each) output port of the filter will be governed by whether polarisation conversion has occurred.

In the case of an acousto-optic filter, the stress-induced birefringence is defined by injecting

RF

into the filter a lower frequency waveform, i.e. electromagnetic energy typically in the range of a few hundred MHz. In the case of an electro-optic filter, the birefrigence is induced by an electrode structure arranged along the wave guide.

An adaptive optical wavelength filter as described above allows for the selective addition or subtraction of a wavelength division multiplexed channel from an optical communication network. The simultaneous addition or subtraction of multiple channels can be achieved by the use of an appropriately configured filter of this kind.

The two types of adaptive optical wavelength filter usually employed in optical networks are known as acousto-optic and electro-optic tunable filters. In the former, a relatively low frequency control signal is applied to the filter, and in the latter, a d.c. control signal is applied to the filter electrode structure, there being a separate electrode structure for each channel. Either kind of filter may be used in the present invention. Both kinds of filter may be configured to have more than one output port and it is preferred to use such a filter, with the channel power determination being performed on the output from one port, and the principal optical signal being propagated from the other output port. Conveniently, for the generation of an appropriate control signal, the output at said one port is the inverse of the output at said other port. Alternatively, the filter may have a single output port and the channel power determination is performed on the optical signal obtained from a passive tapping on the output from that port.

Source Control

In performing the method of this invention, consideration must be given to the locking, in terms of absolute wavelengths, of the filter performing the adaptive filtering and the elements performing the

determination of power levels within the different channels to define the adaption required in the filter. A 'window' could be set, which would be a fraction (perhaps 40%) of the channel separation between the channels. The optical signals transmitted may therefore be anywhere within this 'window' for each channel, and so both the optical filter and the network will need fairly broad responses to these 'windows'. As a result, the filter and channel power determining elements (analyser) will need to be locked tightly only if the responses are well matched. A more relaxed locking requirement would be possible if the analyser has slightly wider 'windows' than the filter. In a case where the analyser takes the form of a passive demultiplexer, this may be achieved by changing the specification of the filters and other components within the demultiplexer. ~~Alternatively,~~ where the analyser comprises a second active filter, a small design change to widen the filter response may be all that is required to achieve a relaxed locking regime, as both filters would, in such an arrangement, be locked to the same driver circuit.

broadly
cl ?
2 filters

The transmission standards for an optical communication network define specific centre wavelengths for the network. Consequently, no locking of the adaptive filters to each other, across the network, should be required.

According to a second aspect of the present invention, there is provided apparatus for controlling the relative amplitudes of the individual wavelength components of a wavelength division multiplexed optical signal, which apparatus comprises an adaptive optical wavelength filter through which the optical signal is passed for processing therein, means to determine the relative powers of the wavelength components of the processed optical signal, control means responsive to

the determined powers of each wavelength component and providing a complex control signal to the adaptive optical wavelength filter which complex control signal includes a control component for each wavelength component of the multiplexed optical signal, the control means controlling the magnitude of each control component dependent upon the determined power of the respective optical signal wavelength component.

In the present invention, the complex control signal has a control component for each wavelength channel of the optical signal, the energy or magnitude of each such component being controlled dependent upon the detected power of each wavelength component of the optical signal. In order to achieve a closed loop feedback system, the relative powers of the individual wavelength components of the optical signal should be determined following the processing of that signal in the adaptive optical wavelength filter.

feedback

When an acousto-optic tunable filter is employed, the control signal will have a frequency component for each channel of the optical signal, the energy of each such frequency component being adjusted in order to control the power of the respective wavelength component of the optical signal. If an electro-optic tunable filter is employed, the control signal will have a d.c. component for each channel of the optical signal, each d.c. component being applied to the respective electrode structure of the filter to control the power of the respective channel of the optical signal, dependent upon the voltage of the applied d.c. control component.

The determination of the power of each channel of a wavelength division multiplexed optical signal may be performed by any suitable manner known in the art. For example, in-line optical filters may be employed to separate a portion of the optical signal into its

individual wavelength components, the amplitude of each of which then being determined for instance by an individual photo-detector for each channel. Instead of the use of optical filters, a wavelength division demultiplexer may be employed to separate a portion of the optical signal into individual wavelength components.

The determination of the power of each channel of the optical signal may instead be determined by a further adaptive optical wavelength filter similar to that employed to control the magnitude of each wavelength component of the optical signal. Such a further filter may sample each channel of the optical signal, in sequence, the output of the further filter sequentially corresponding to the power of each channel of the optical signal. By linking the two filters to the same driver circuit, the operation of the two filters will be closely locked to each other and the signal wavelengths being analysed. With this arrangement, the two filters could be arranged on one integrated circuit.

The magnitude of each control component of the control signal may be adjusted such that the relative powers of each wavelength component of the optical signal are, after processing in the filter, substantially the same. Alternatively, when the processed optical signal is subsequently to be processed through a non-linear component such as an optical amplifier, each control component of the control signal may be adjusted having regard to the transfer function of the subsequent non-linear component. In this way, the power of all wavelength channels of the optical signal may be controlled so as to be essentially the same, following processing through the non-linear component.

equalize

By way of example only, the invention will now be

described in greater detail and certain specific examples thereof given, reference being made to the accompanying drawings, in which:-

Figure 1 schematically shows a network for the processing of wavelength division multiplexed optical signals;

Figure 2 diagrammatically illustrates a first example of a method of this invention;

Figure 3 diagrammatically illustrates a second example of a method of this invention, similar to that of Figure 2;

Figure 4 diagrammatically illustrates a third example, using a filter to analyse the channel wavelengths;

Figure 5 illustrates yet another example, similar to that of Figure 4;

Figure 6 shows the transfer function of an adaptive filter, showing the slewing of power between the secondary and main outputs of the filter, as used in the embodiment of Figure 2; and

Figures 7A and 7B compare the output signals from a non-linear optical amplifier, respectively without and with adaptive balancing according to this invention.

Figure 1 diagrammatically illustrates a network including a plurality of switching nodes 10 for optical signals propagated along optical fibres 11. The signals may be multi-channel wavelength division multiplexed signals and so there may be a plurality of wavelengths appearing at any one or more of the nodes 10. For example, fibre 12 may be carrying a channel of wavelength $\lambda 1$ and of amplitude $\alpha 1$, and fibre 13 a channel of wavelength $\lambda 2$ and amplitude $\alpha 2$. If these channels are switched both to appear on fibre 14 as a wavelength division multiplexed signal, though both signals had the same amplitude on entering the network,

following the processing through the nodes, the relative amplitudes of the two channels will be as shown at $\alpha 3$. Upon subsequent processing of that multiplexed signal, the difference in the amplitudes of the two channels will be exacerbated, leading to possible difficulties in recovering the smaller amplitude channel.

Figure 2 shows the processing of a wavelength division multiplexed signal with channel amplitudes out of balance, such as the signal on fibre 14 of Figure 1. An electro-optic or acousto-optic adaptive filter 20 has an input port 21 and main and secondary output ports 22 and 23 respectively. The filter further has a control port 24. Such a filter is known per se in the art and will not be described in further detail here.

Optical fibre 14 carrying a wavelength division multiplexed signal is connected to the input port 21 and a further fibre to the main output port 22. All of the input channels appear at both the main and secondary ports, but the signal from the secondary port 23 is supplied to a wavelength demultiplexer (not shown, but known per se in the art) in order to provide individual channel components to a group of photo-detectors 25, with one channel component supplied to each photo-detector respectively. The photo-detectors each determine the power of the channel component supplied thereto and in turn provide an output to a control circuit 26. That circuit 26 controls the operation of a plurality of oscillators 27, one oscillator for ~~each~~ wavelength channel of the input signal; the outputs of the oscillators 27 are combined at 28 and supplied to the control port 24 of the filter. RF

Figure 3 shows an arrangement similar to that of Figure 2, but the adaptive filter 20 has only a main output port 22. The input to the channel power

analyser section of the arrangement is taken from a passive tapping 29 on the main output from the filter. In all other respects this arrangement corresponds to that of Figure 2 and will not be described in further detail here.

The third embodiment shown in Figure 4 employs a channel power analyser section utilising a second adaptive wavelength filter 30 the input port 31 of which is connected to the secondary output port 23 of the principal adaptive filter 20. A single control circuit 32 controls the operation of two separate sets 33 and 34 of oscillators, the two sets of oscillators being associated with the two adaptive filters 20 and 30 respectively. The outputs of the oscillators of each set are combined at 35 and 36 respectively and the resultant control signals are supplied to the control ports 24 and 37 respectively, of the two adaptive filters 20 and 30.

The output of the adaptive filter 30 is supplied to a single photo-detector 38 and the signal indicative of the power of the channel component instantaneously supplied to the photo-detector 38 is fed to the control circuit 32, in order to control the appropriate oscillator of the set 33 associated with the filter 20. In this way, the powers of the various wavelengths in the signal leaving the main output port of the filter 20 may be balanced as required, with the analysis of the powers of the channels being performed using the further adaptive filter 30 for sampling the channels one at a time, in sequence, under the control of circuit 32. By using a single control circuit 32, the operation of the embodiment may properly be synchronised to ensure that the transfer function of the filter 20 for each channel is properly matched to the detected power of that channel.

Figure 5 illustrates a further embodiment similar

to that of Figure 4 in that a second adaptive filter 30 is employed to perform the analysis of the multi-channel signal passing through the filter 20. In this case, rather than providing two separate sets of oscillators a single set 40 is arranged to control both filters 20 and 30. For controlling the filter 20, the outputs from the oscillators are passed through elements 41 the effective resistance of which can be varied by the control circuit 32, before the outputs are combined and supplied to the control port 24 of filter 20. An output is also taken from each oscillator to a switch circuit 43, the operation of the switch being performed by the control circuit 32 so that the appropriate oscillator output is supplied to the control port of filter 30 in a timed relationship to the operation of the oscillators.

In other respects, the operation of the embodiment of Figure 5 corresponds to that of Figure 4 and will not be described further here.

Figure 6 shows, for the embodiments any of Figures 2, 4 or 5, the relationship between the optical powers appearing at the main and secondary ports 22 and 23, for any one wavelength channel of a signal supplied to the input port 21, when a suitable high frequency control signal is supplied to the control port 24. By adjusting the energy of the control signal, the transfer function of the filter for the channel associated with the frequency of the control signal can be varied. The power of the output signal at the secondary port 23 is the inverse of the power of the signal at the main output port 22.

By suitably varying the energy of the control signal, the power of the optical signal at the main output port 22 may be controlled to have a desired value. Such control is performed dependent upon the determined power of the signal from the secondary

output port 23. The control circuit may thus be configured to define a closed loop system to ensure the power of the optical system at the main output port is maintained constant at a desired value, irrespective of variations in the power of the optical signal at the input port 21.

Figure 7A shows the effect of a typical non-linear optical amplifier 45 on a wavelength division multiplexed optical signal the relative powers of the individual channels of which are as shown at 46. As can be seen at 47, following processing by the amplifier 45, the relative imbalance in the channel powers is increased. However, by subjecting the input signal to the amplifier 45 to adaptive balancing by the method and apparatus of this invention as described above, the relative powers of the channels of the output signal from the amplifier 45 may all be substantially the same, as shown in Figure 7B at 48.

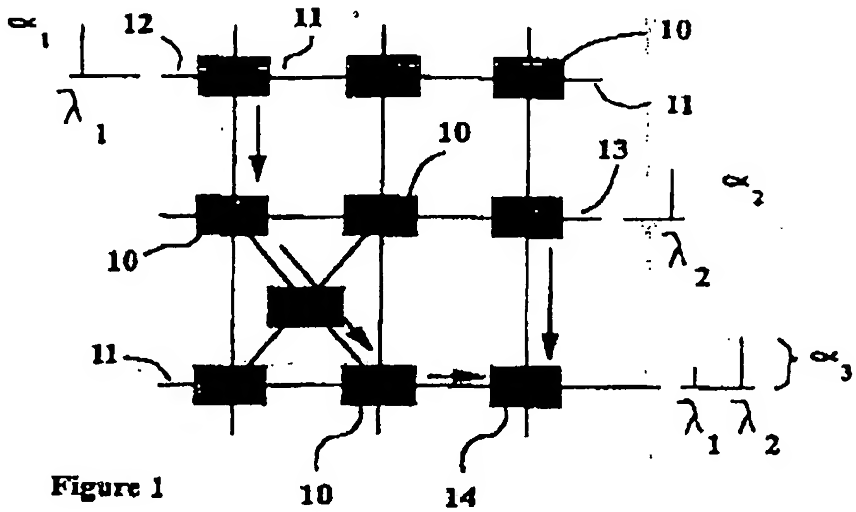


Figure 1

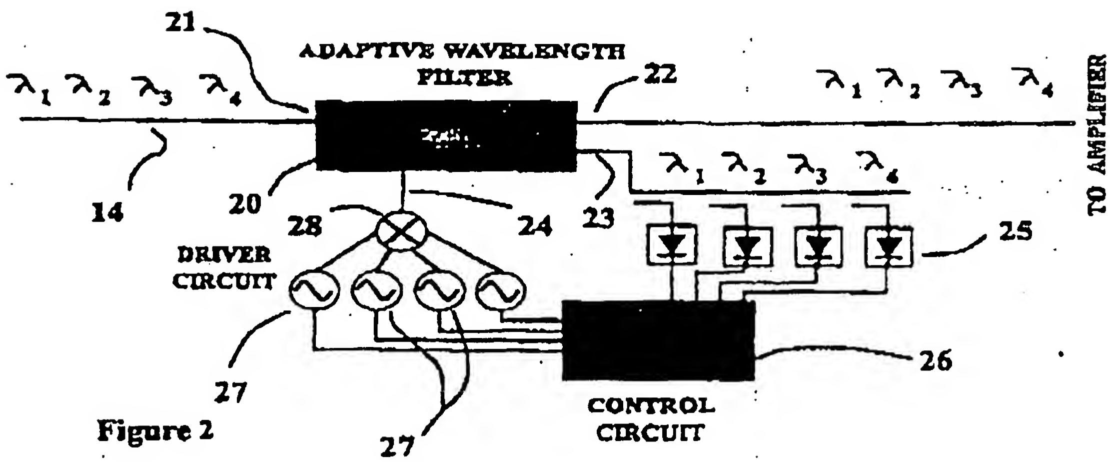


Figure 2

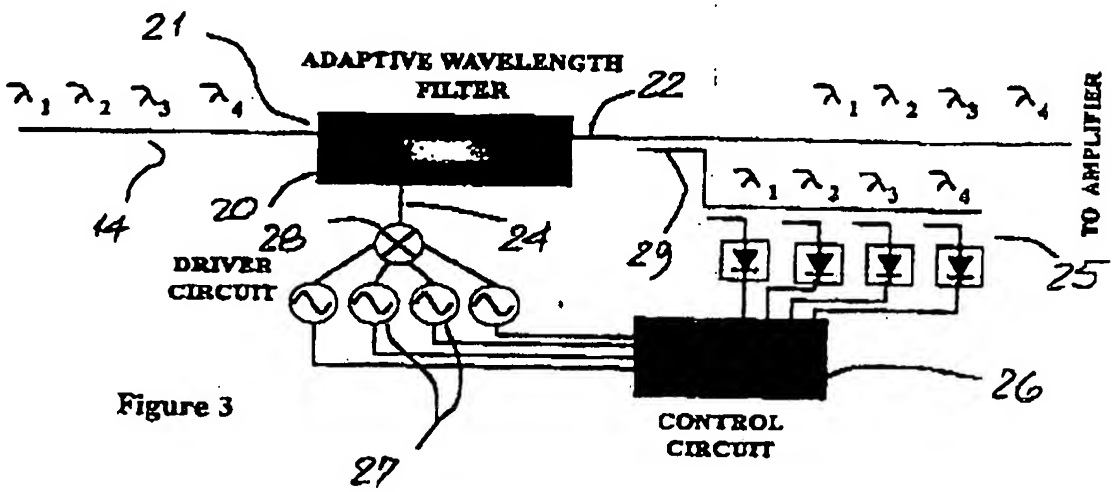


Figure 3

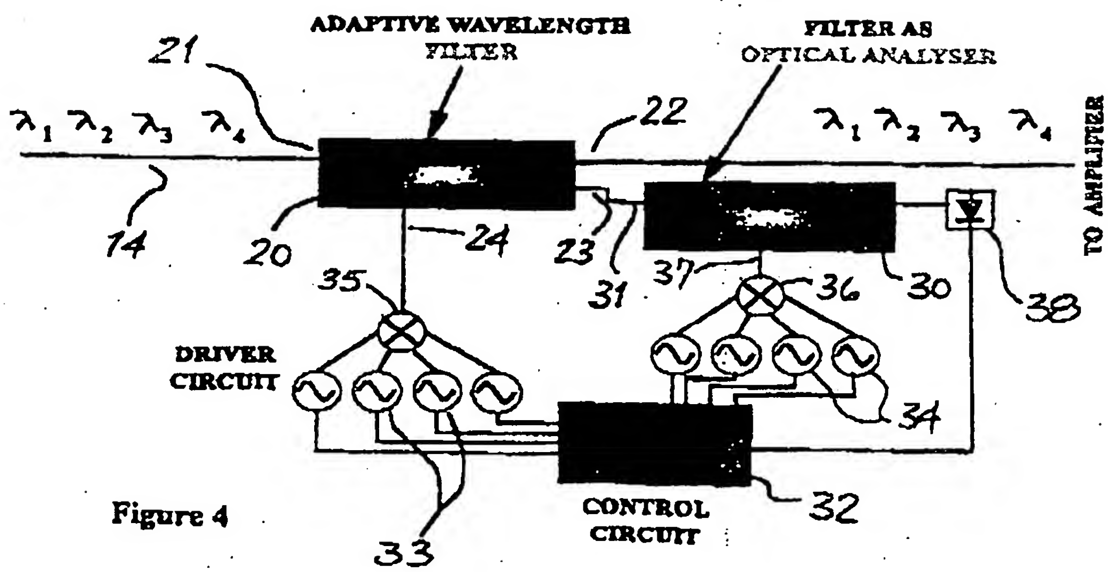


Figure 4

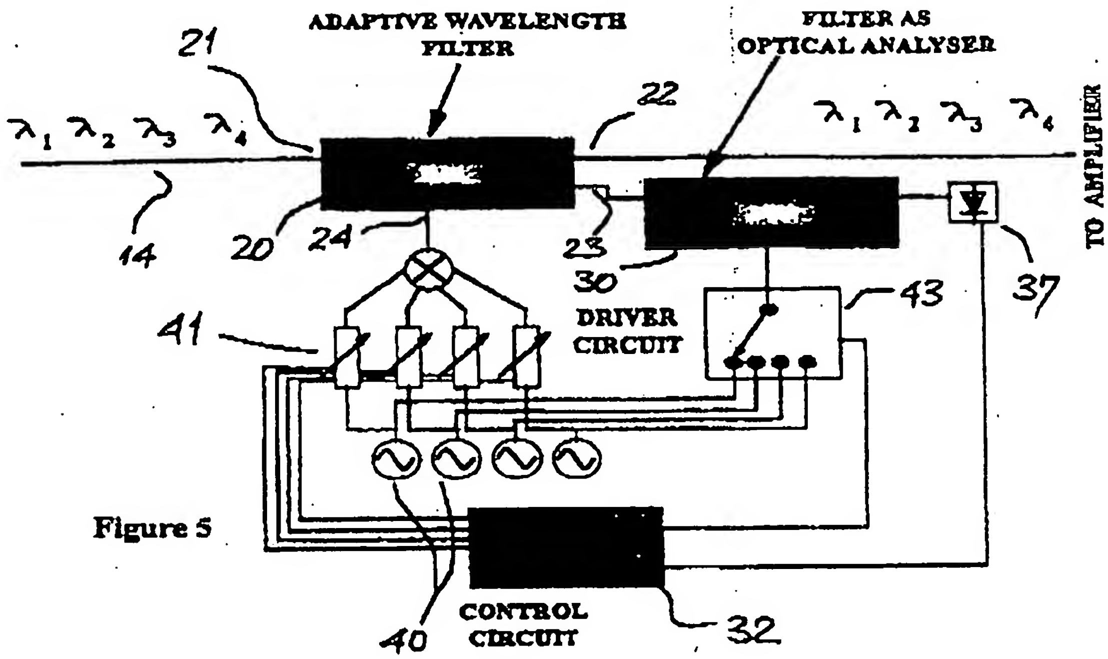


Figure 5

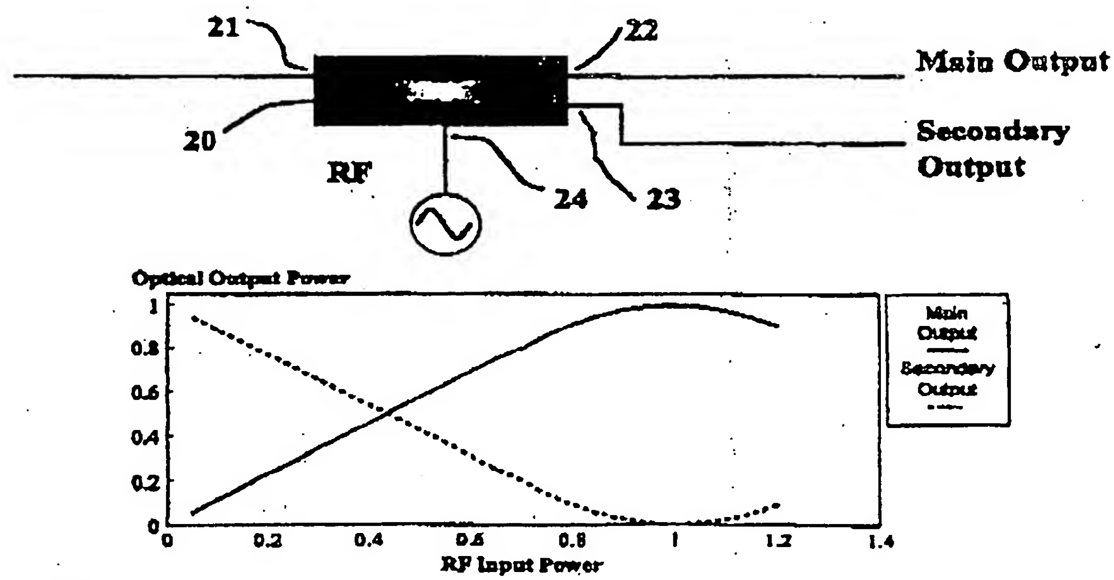


Figure 6

Figure 7a

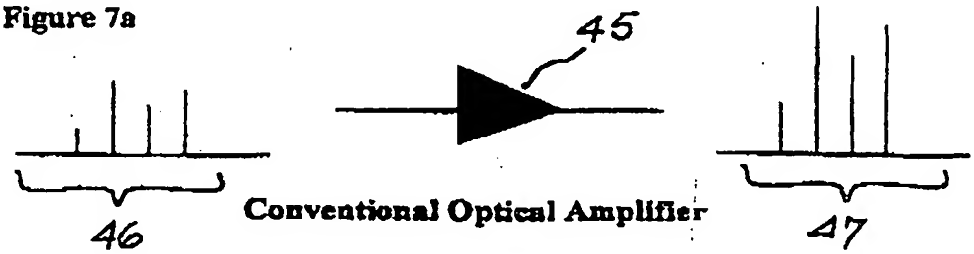
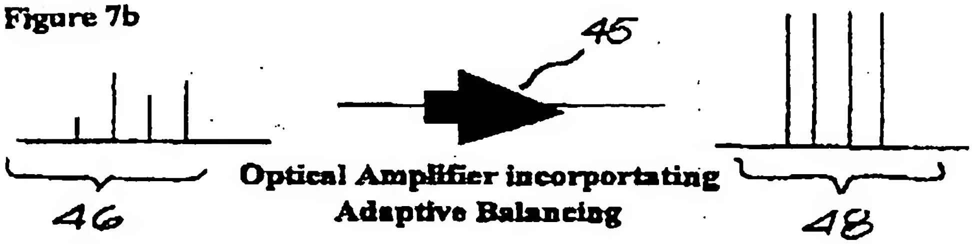


Figure 7b



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 96/02278

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04J14/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04J H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP,A,0 637 148 (NORTHERN TELECOM LTD) 1 February 1995	1,2,7-13
Y	see column 1, line 1 - column 2, line 5 see column 2, line 16 - column 3, line 35 see column 3, line 42 - column 4, line 1 see column 4, line 28 - line 31 ---	3-6,14,15
Y	EP,A,0 475 016 (HITACHI LTD) 18 March 1992 see abstract see column 3, line 37 - column 4, line 9 see column 4, line 39 - line 58 ---	3-6,14,15
A	EP,A,0 467 396 (CANON KK) 22 January 1992 see abstract see column 2, line 1 - column 3, line 16 see column 5, line 1 - line 40 ---	1,2,13

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
6 December 1996	13.01.97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+ 31-70) 340-3016	Chauvet, C

INTERNATIONAL SEARCH REPORT

International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	IEE PROCEEDINGS J. OPTOELECTRONICS, vol. 140, no. 5, PART J, 1 October 1993, pages 275-284, XP000412788 WEBER J -P: "SPECTRAL CHARACTERISTICS BRAGG-REFLECTION TUNABLE OPTICAL FILTER" see abstract and introduction -----	10-12